US006485293B1

(12) **United States Patent**
Li et al.

(10) **Patent No.: US 6,485,293 B1**
(45) **Date of Patent: Nov. 26, 2002**

(54) **BURNER ASSEMBLY WITH ENHANCED BTU OUTPUT AND FLAME STABILITY**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/631,084**

(22) Filed: **Aug. 2, 2000**

(51) **Int. Cl.**[7] **F23D 14/22**

(52) **U.S. Cl.** **431/266**; 431/265; 239/429; 239/434; 239/498

(58) **Field of Search** 431/263, 264, 431/265, 266, 278, 284, 353, 347; 239/418, 423, 424.5, 425, 426, 429, 430, 431, 432, 433, 434, 498; 301/104, 64.1

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,209,261 A * 12/1916 Challiner 301/104
2,465,155 A * 3/1949 Higley 431/174
3,469,790 A * 9/1969 Duncan 431/265
3,700,173 A * 10/1972 Ketchum, Jr. 239/498
5,494,437 A * 2/1996 Kubota et al. 431/181
5,984,665 A * 11/1999 Loftus et al. 431/278
6,041,838 A * 3/2000 Al-Sabah 152/55

FOREIGN PATENT DOCUMENTS

GB 1304794 * 1/1973 .... 431/264
JP 6-221528 A * 8/1994

* cited by examiner

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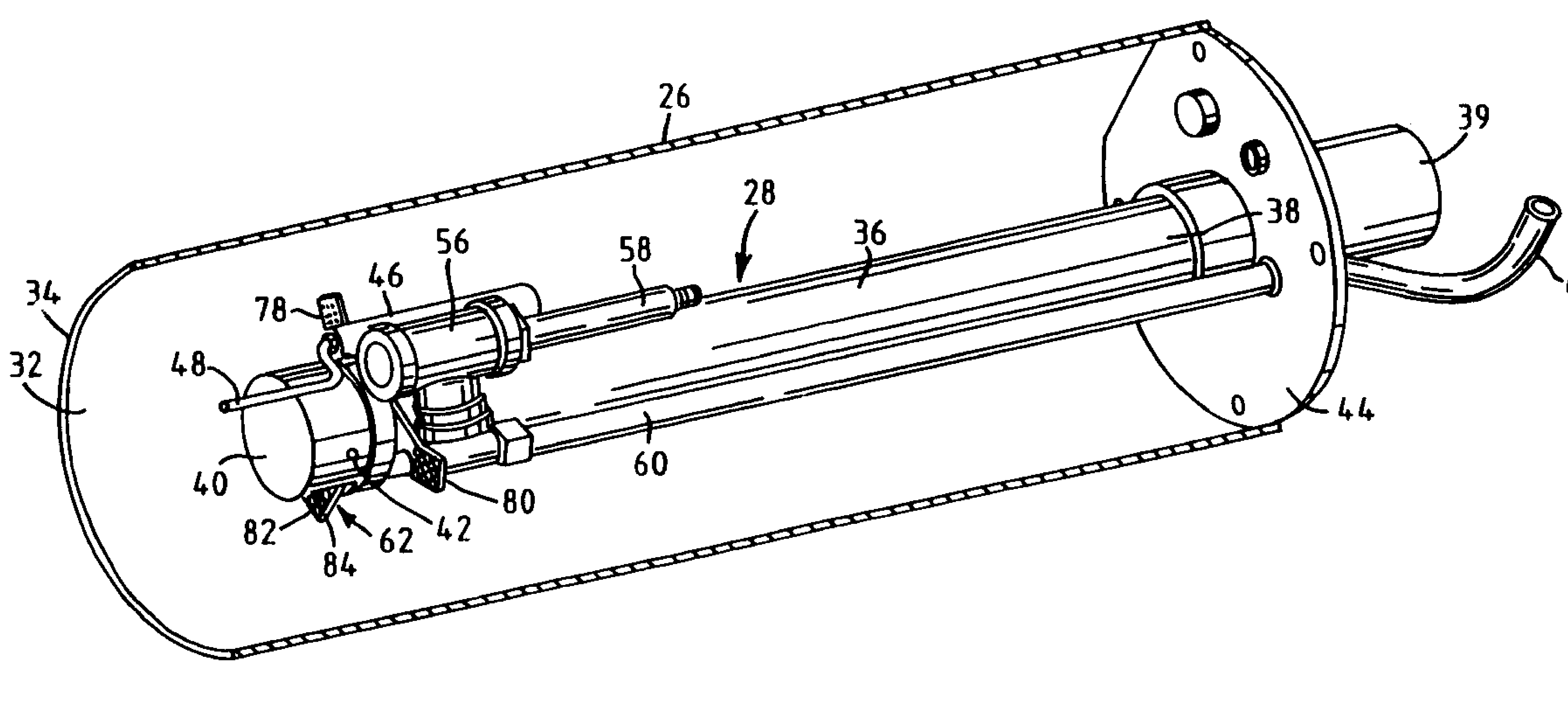
(57) **ABSTRACT**

A burner assembly having improved BTU output, flame stability and starting reliability is provided. The burner includes a retention plate at an output end of a gas supply line having a central hub from a which a plurality of spokes radially extend. The retention plate and gas supply line are provided within an outer sleeve of the burner. The retention plate occupies a relatively small cross-sectional area of the sleeve. Accordingly, large amounts of combustion air can be forced through the sleeve, with controlling air flow paths being created by apertures provided in each of the spokes. A pilot, including a circumferential spark gap, is provided to improve starting reliability.

17 Claims, 4 Drawing Sheets



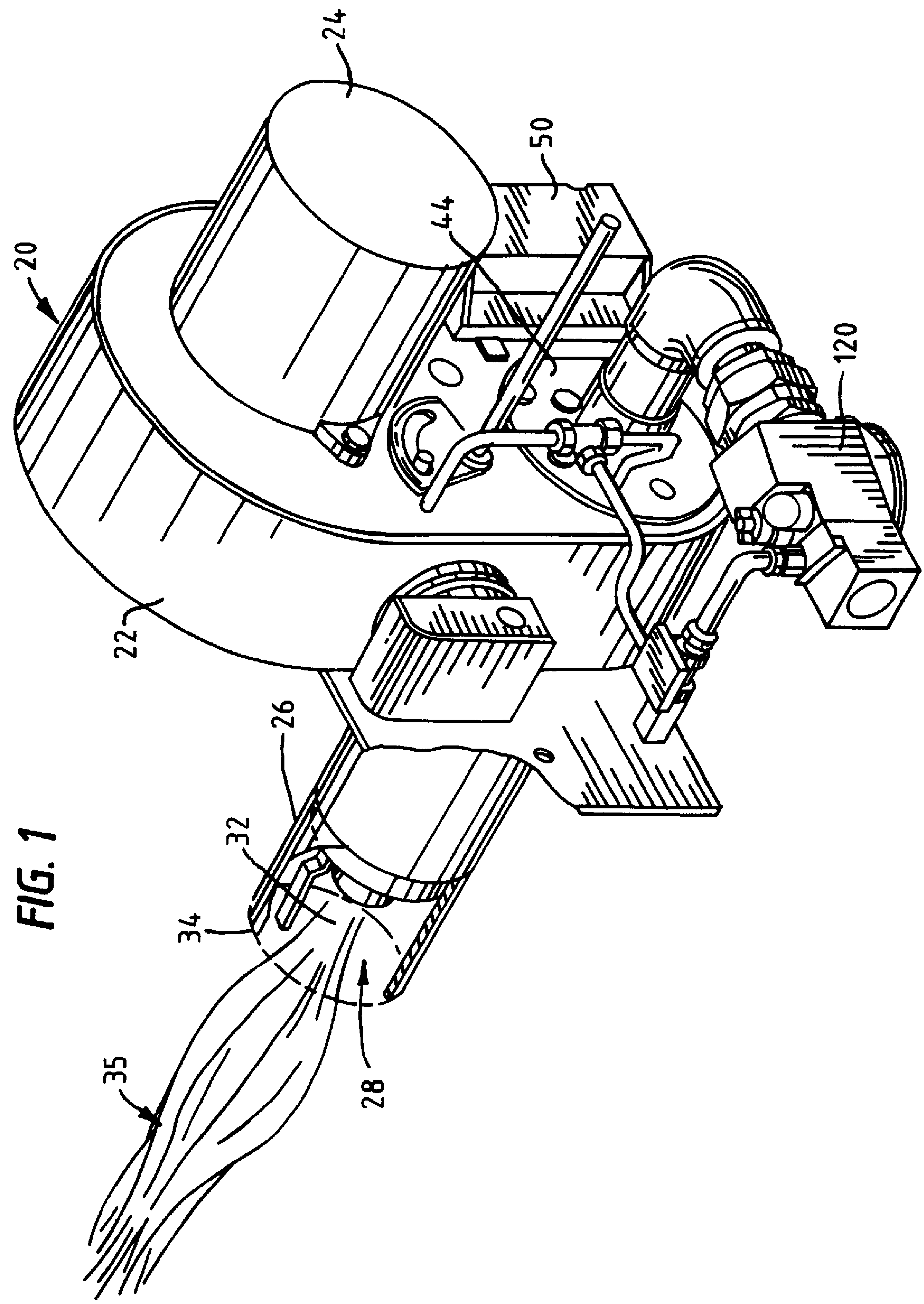


FIG. 1

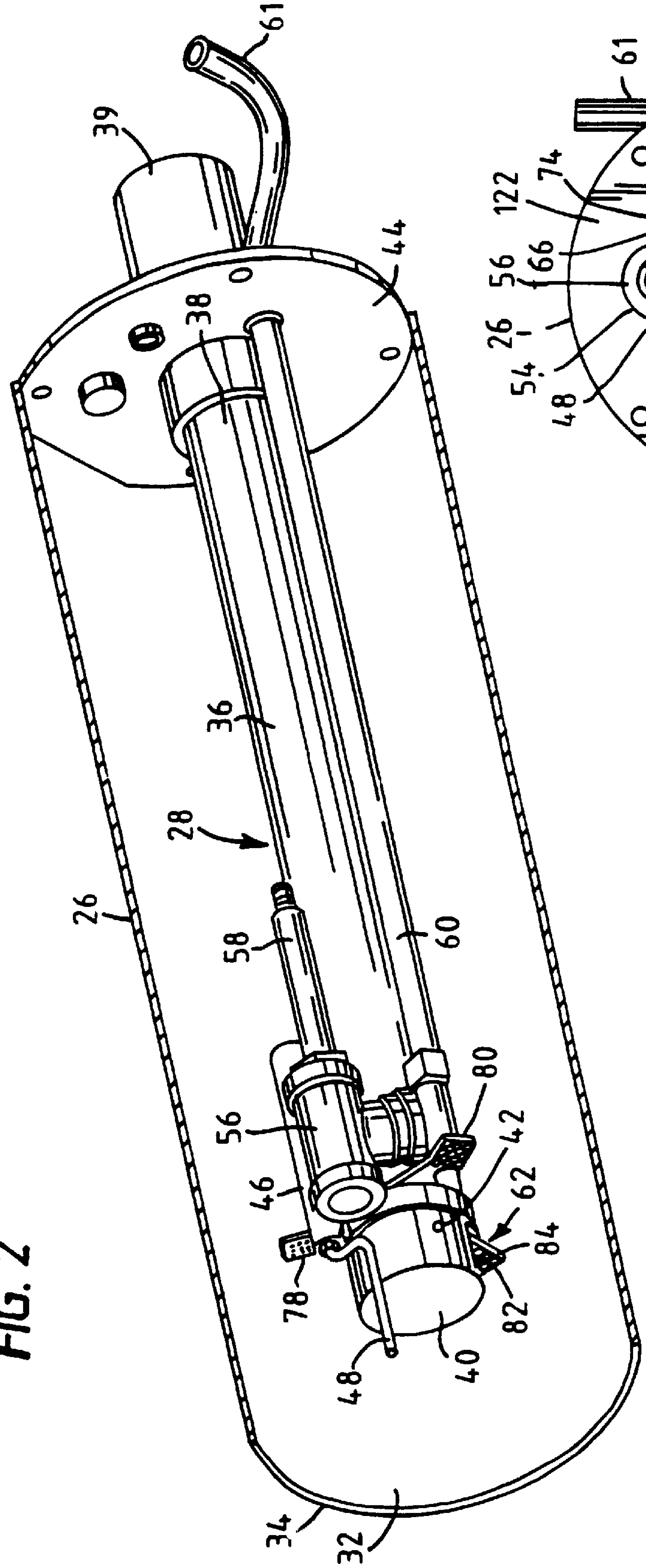

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FIG. 2

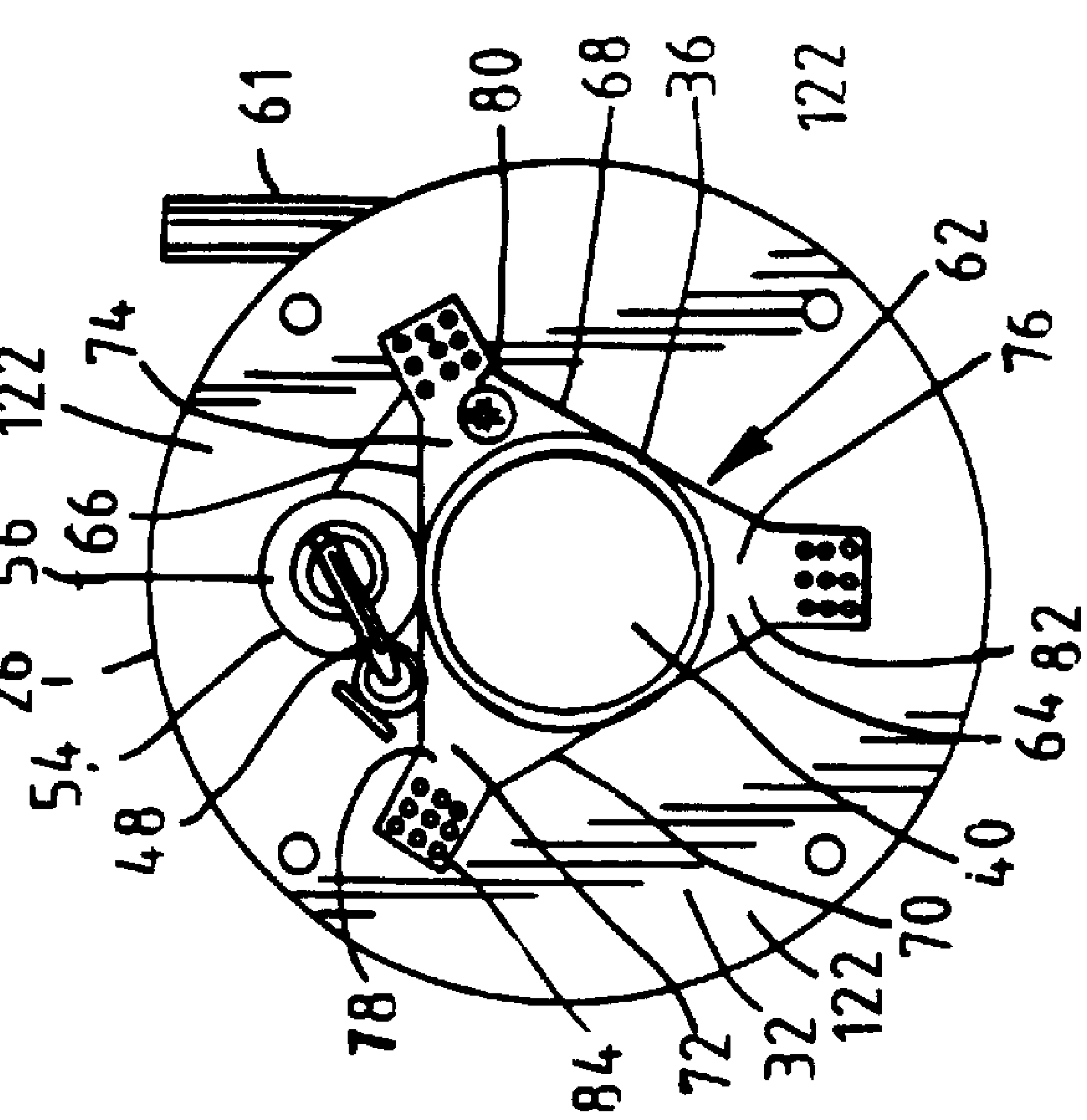
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FIG. 3

FIG. 4

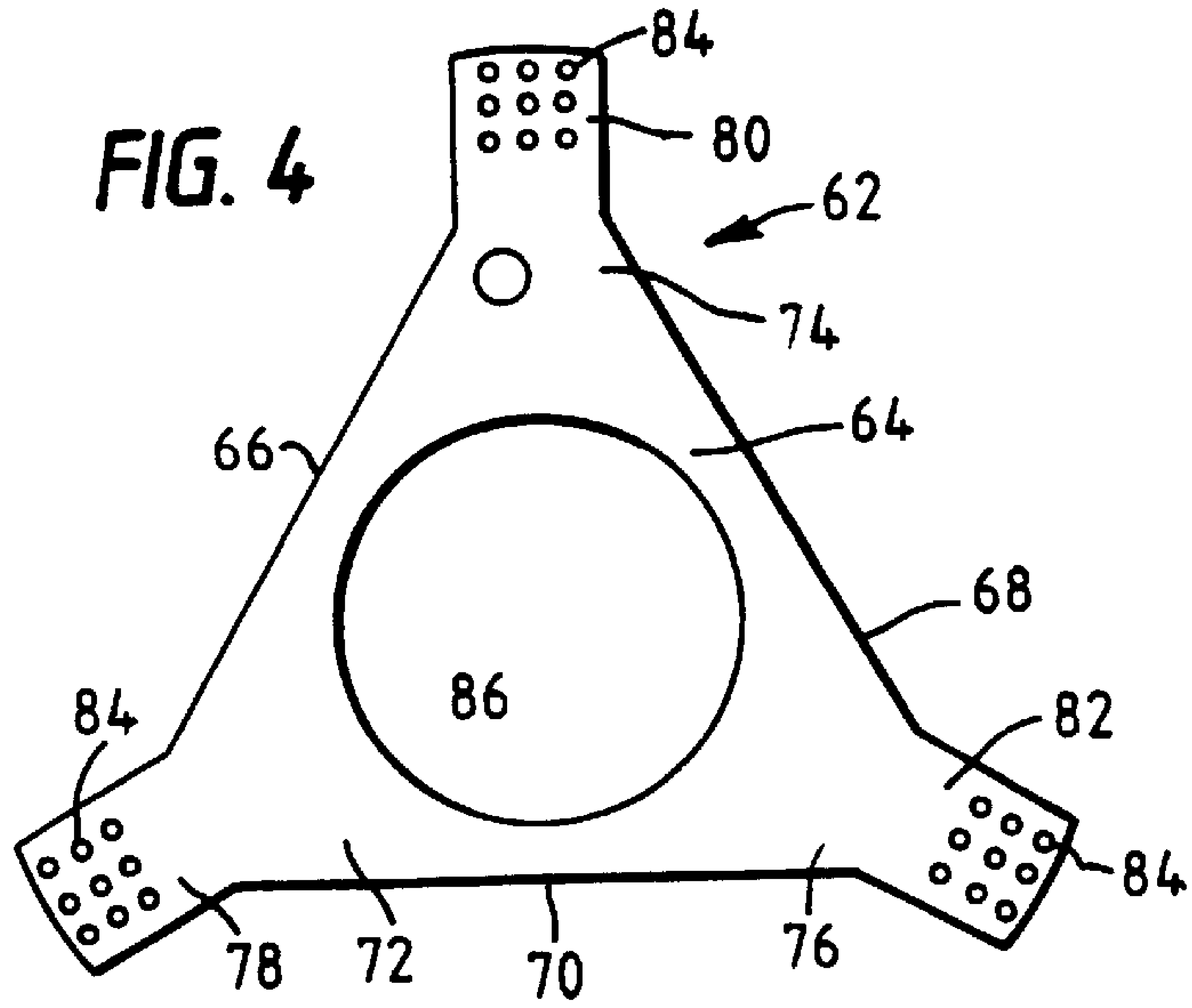

FIG. 7

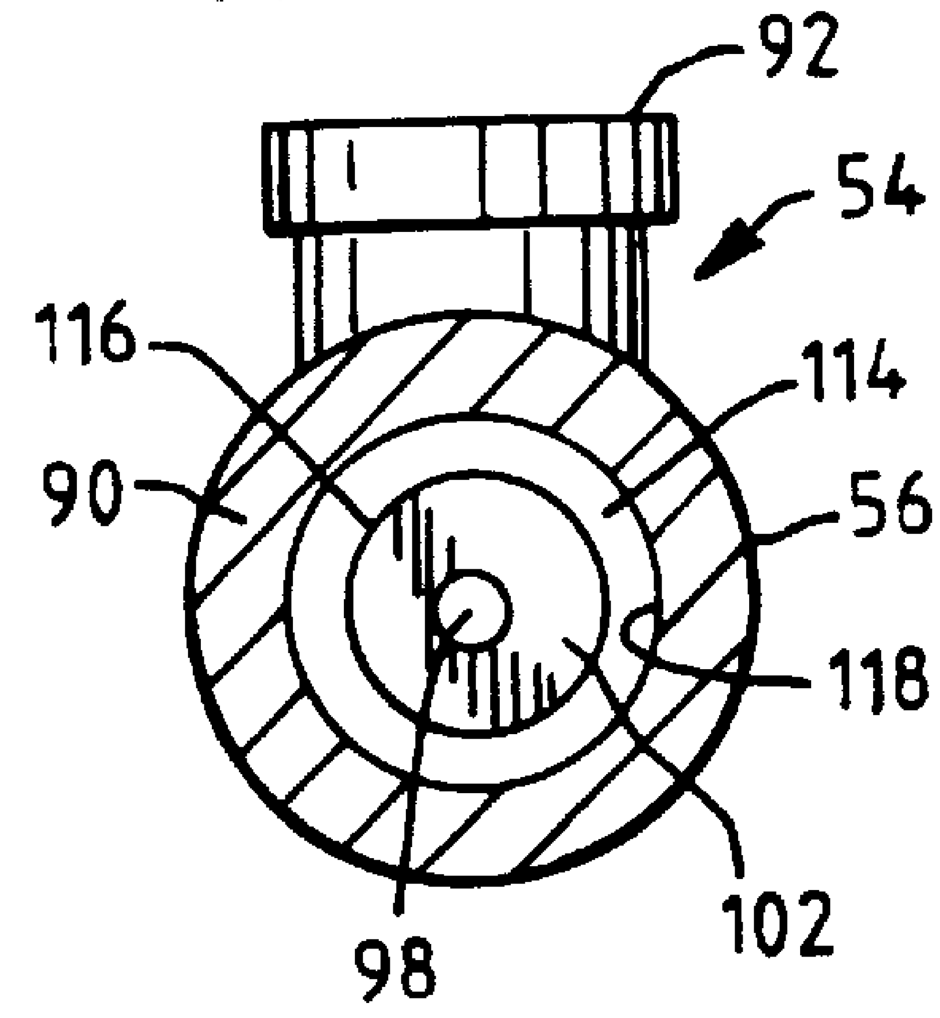

FIG. 5

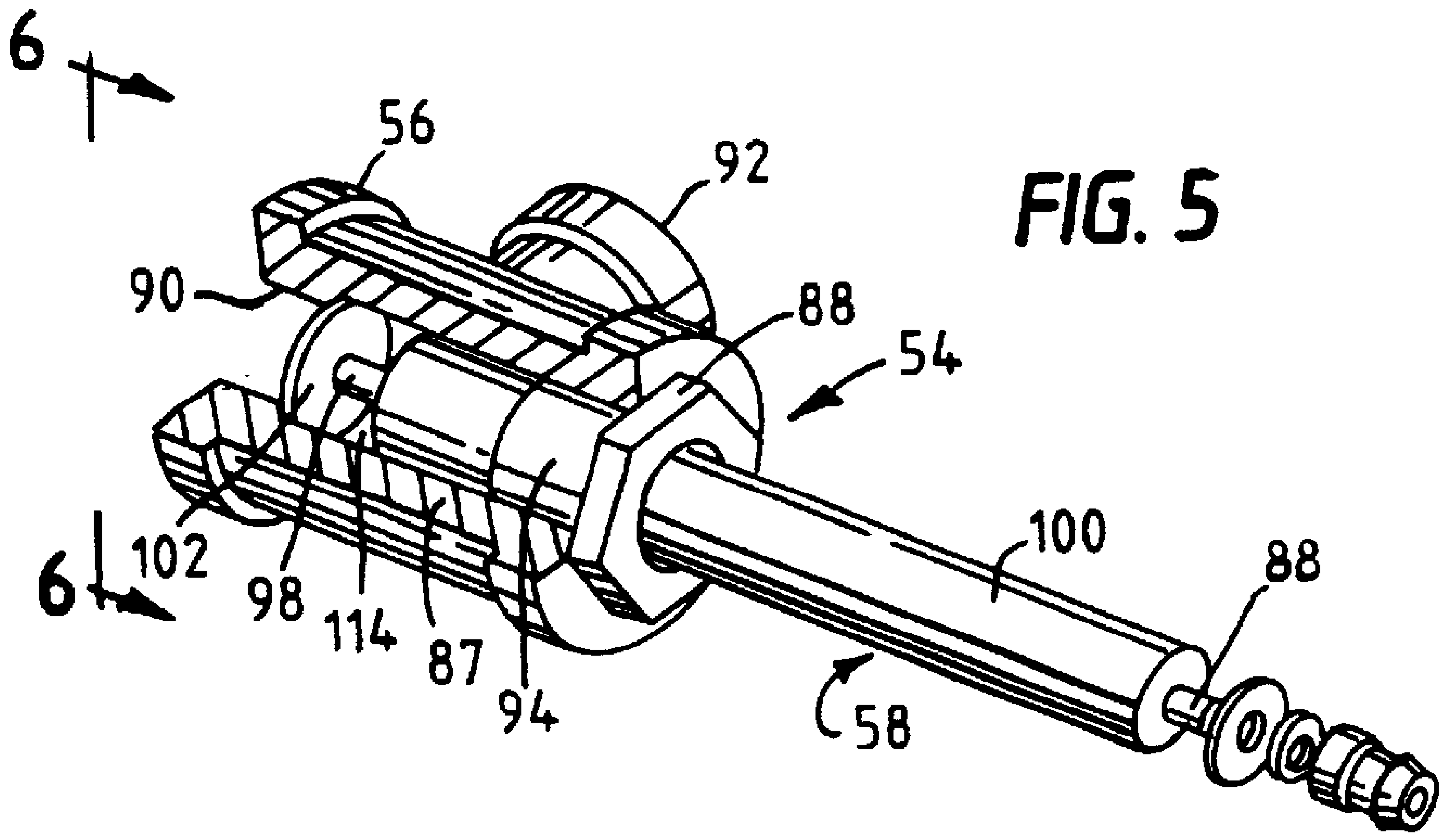

FIG. 6

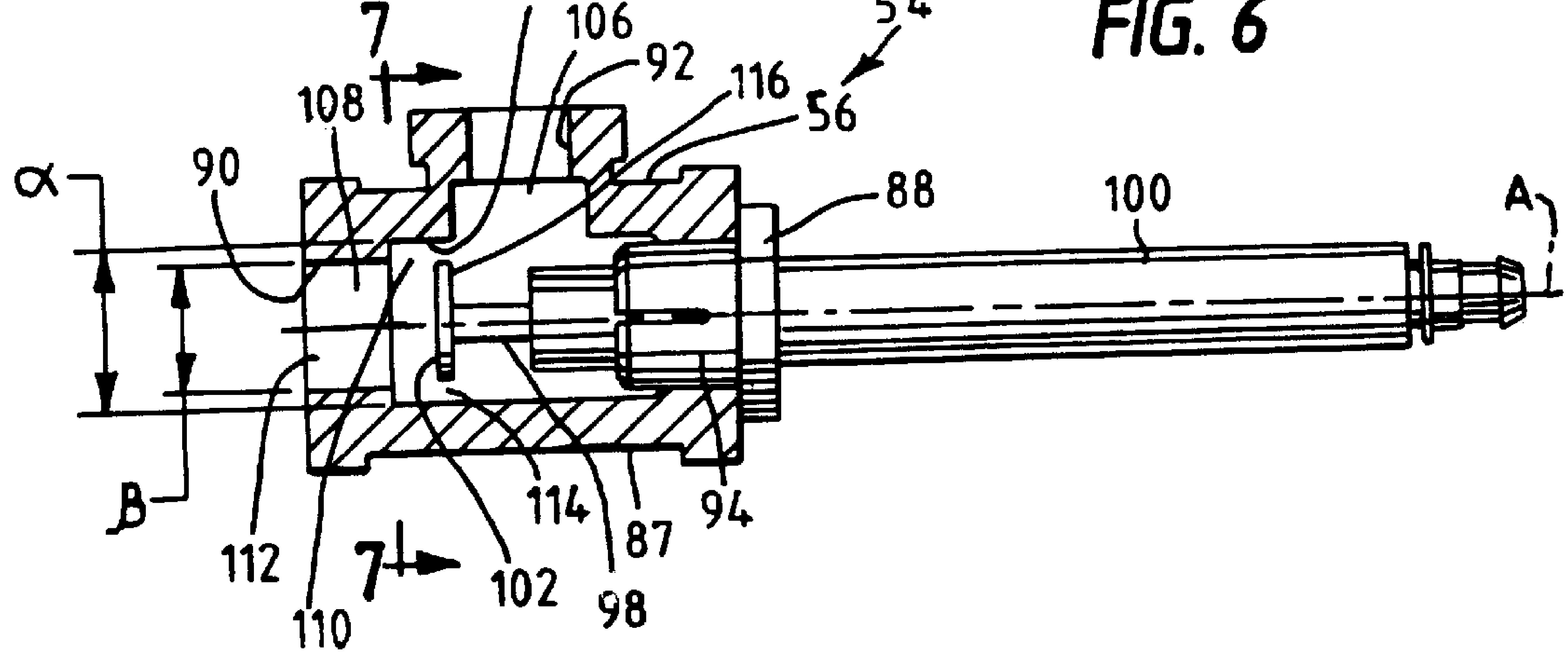

FIG. 8

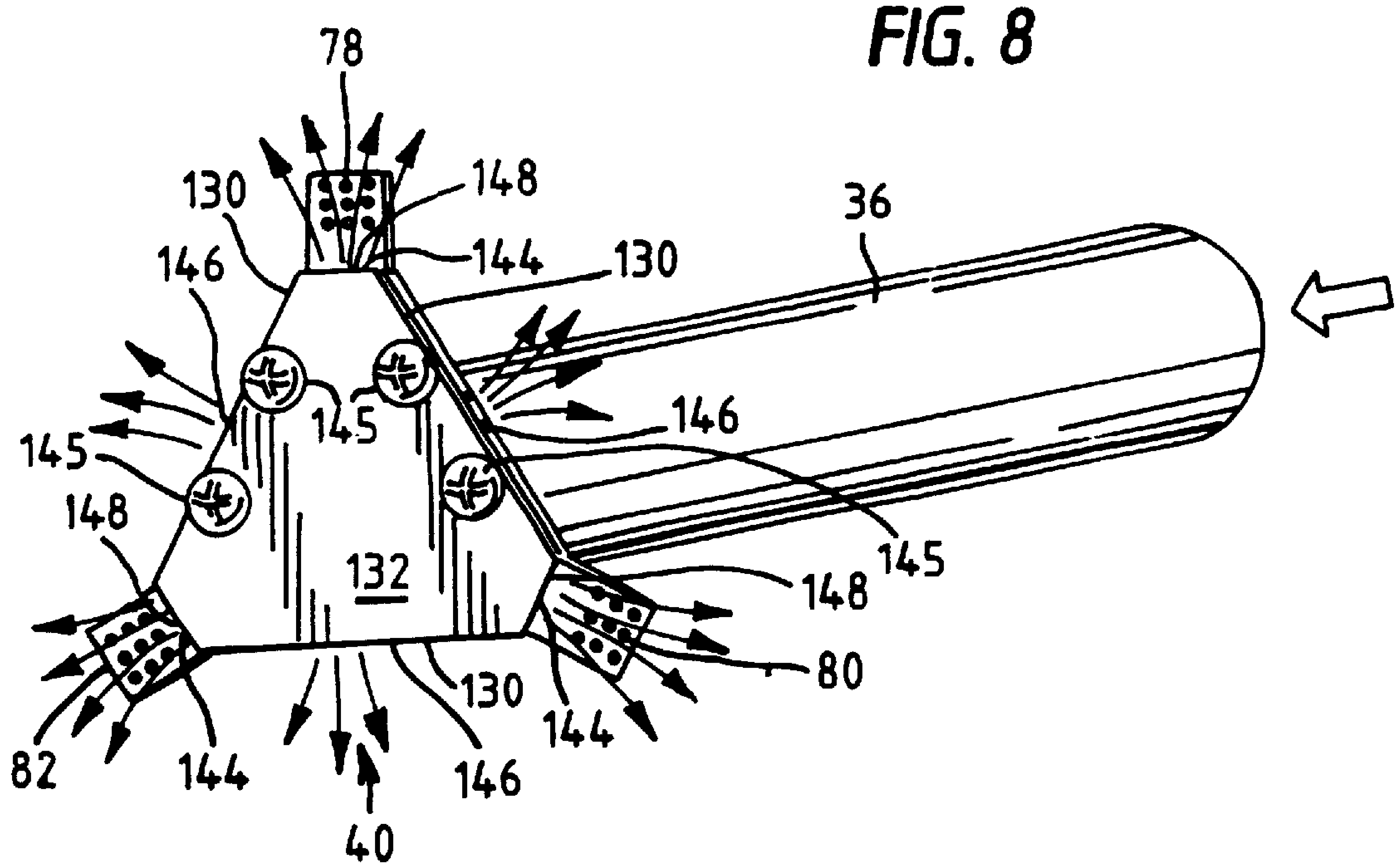
78
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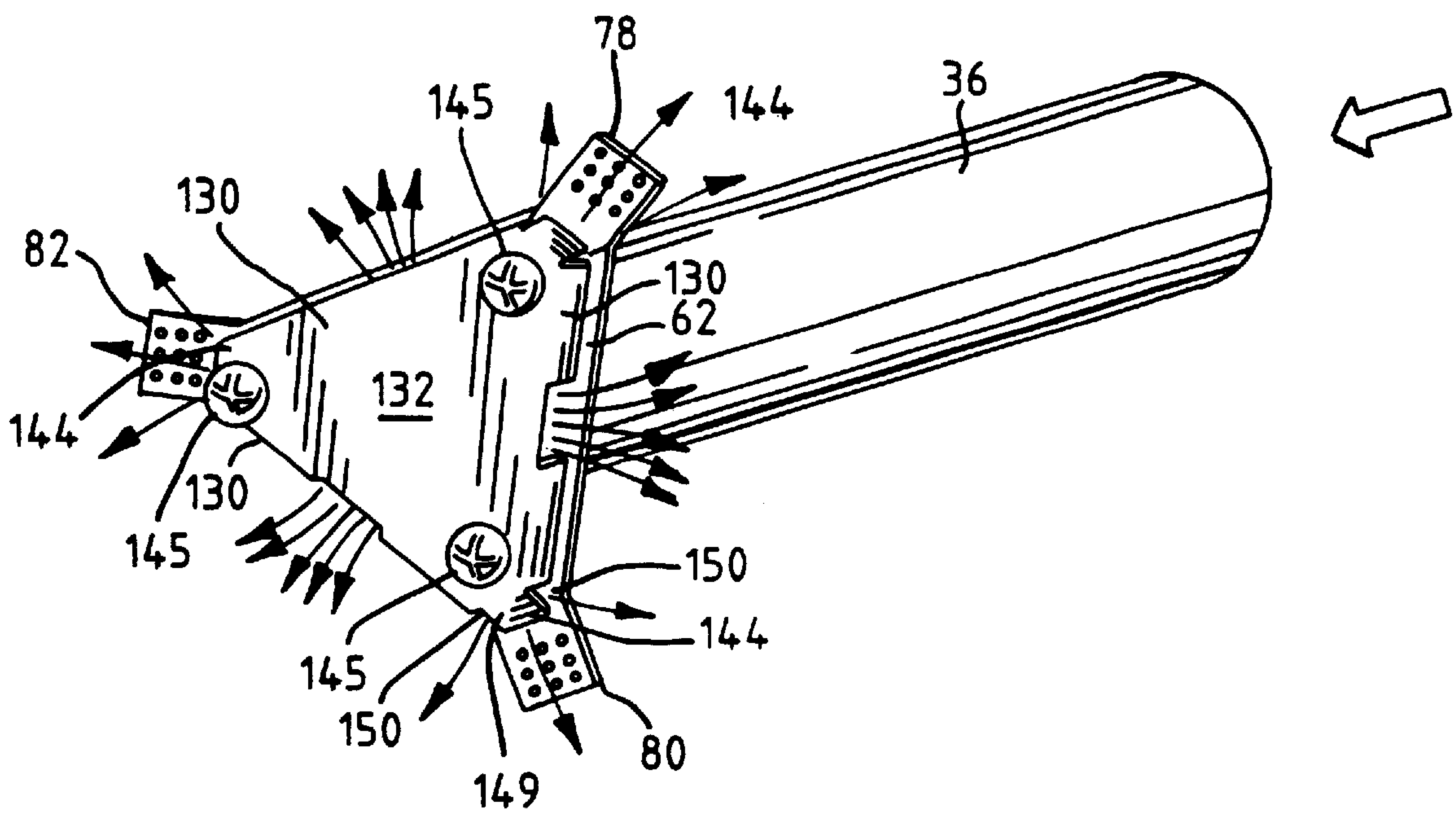
FIG. 9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BURNER ASSEMBLY WITH ENHANCED BTU OUTPUT AND FLAME STABILITY

FIELD OF THE INVENTION

The invention generally relates to gas burners and, more particularly, relates to gas burner assemblies.

BACKGROUND OF THE INVENTION

Burners which combust gas, such as propane and natural gas, are well known and widely applied. For example, boilers, furnaces, kilns, incinerators, dryers, and food processing equipment all commonly rely upon the heat generated by such combustion for proper operation.

Prior art burner designs have been created to mix a combustible gas with air and provide a spark for the purpose of starting. Extensive attention has been directed to finding proper mixing ratios and to creating apparatus for obtaining such ratios to most efficiently burn the gas while maximizing BTU output.

One known type of burner includes a substantially cylindrical housing provided with an inlet and an outlet. A motor connected to a blower or a fan wheel is typically connected to the inlet to direct air needed for combustion therethrough. A gas supply conduit typically enters the inlet end of the housing as well, and terminates in a gas nozzle short of the housing outlet end. The area of the housing downstream of the nozzle defines a combustion chamber. An ignition source, such as a spark plug or rod, is positioned proximate the gas nozzle and can be energized as needed.

In order to generate a desired airflow through the housing to the combustion chamber to obtain the desired BTU output and flame shape, various retention or nozzle plates have been created. Such plates are typically provided transverse to the longitudinal axis of the housing, and are positioned slightly upstream of the nozzle. The plates typically include various aperture designs to direct forced air therethrough and thus create desired characteristics in the resulting flame.

Two such characteristics are BTU output and flame stability. BTU output is a measure of the strength of the flame and its resulting heat output, and is a function of, among other things, the amounts of air and gas combined and the ratio at which they are combined. Flame stability relates to the maintainability and controllability of the flame. If the gas/air ratio becomes too rich or too lean, the flame can be lost or can burn inefficiently. If the flame is not suitably confined, shaped, and directed, BTU output may be detrimentally effected.

In light of the foregoing, various aperture sizes, aperture patterns, and angles of incidence have been employed in prior art retention plates. Moreover, to ensure starting reliability, relatively complex pilot assemblies have typically been employed. Such pilots require extensive machining and assembly time, resulting in an expensive pilot.

SUMMARY OF THE INVENTION

In accordance with one aspect of the invention, a burner assembly is provided which comprises a substantially cylindrical combustion chamber, a gas supply provided in the combustion chamber and terminating in the gas supply outlet, an air supply in fluid communication with the combustion chamber, and a flame stabilizing plate disposed in the substantially cylindrical combustion chamber. The flame stabilizing plate includes a central hub from which a plurality of spokes radially extend. Major combustion air openings are defined by adjacent spokes and the combustion chamber. Minor combustion air openings are provided in each of the plurality of spokes.

In accordance with another aspect of the invention, a pilot assembly is provided which comprises a housing having a combustion chamber, a spark rod having an end plate disposed in the combustion chamber and spaced from an interior surface of the combustion chamber to form a circumferential sparking gap around the end plate, and a gas supply inlet in fluid communication with the combustion chamber.

In accordance with another aspect of the invention, a burner nozzle plate is provided which comprises a central hub, and a plurality of spokes extending radially from the central hub.

In accordance with another aspect of the invention, an improvement to a burner assembly of the type having a nozzle housing having an inlet and an outlet, a blower motor connected to the inlet, a gas supply conduit disposed in the nozzle housing, and a combustion chamber defined by the nozzle housing downstream of the gas supply conduit, is provided. The improvement comprises a nozzle plate disposed in the nozzle housing wherein the nozzle plate includes a central hub with a plurality of spokes radially extending therefrom, each spoke including at least one aperture, a plurality of major air pathways defined by adjacent spokes and the nozzle housing, and at least one minor air pathway defined by each of the spoke apertures.

These and other aspects and features of the invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an isometric, partial cut-away, view of a burner assembly constructed in accordance with the teachings of the invention;

FIG. **2** is an isometric, partial cut-away, view of the burner assembly shown in FIG. **1**;

FIG. **3** is a end view of FIG. **2**;

FIG. **4** is a plan view of a flame retention plate constructed in accordance with the teachings of the invention;

FIG. **5** is an isometric, partial cut-away, view of a pilot assembly constructed in accordance with the teachings of the invention;

FIG. **6** is a sectional view of FIG. **5** taken generally along line **6**—**6** of FIG. **5**;

FIG. **7** is an end view of a pilot assembly constructed in accordance with the teachings of the invention;

FIG. **8** is an isometric view of an alternative embodiment for a gas outlet cap constructed in accordance with the teachings of the invention; and

FIG. **9** is an isometric view of another alternative embodiment for a gas outlet cap constructed in accordance with the teachings of the invention.

While the invention is susceptible to various modifications and alternative constructions, certain illustrative embodiments thereof have been shown in the drawings and will be described below in detail. It should be understood, however, that there is no intention to limit the invention to a specific form disclosed, but on the contrary, the intention is to cover all modifications, alternative constructions and equivalents falling within the spirit and the scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, and with specific reference to FIG. **1**, a burner constructed in accordance with the teachings of the invention is generally depicted by reference numeral **20**. A shown therein, the burner **20** includes a housing **22** in which a blower fan (not shown) is adapted to rotate. The fan is powered by a motor **24**. An air flow created by the blower fan is directed through a sleeve or nozzle housing **26** which is shown to be substantially cylindrical in shape. A burner cartridge assembly **28** is disposed within the sleeve **26** to supply combustible gas and a source of ignition. The burner **20** is primarily directed to combustion of propane, but it is understood that other gases, including but not limited to natural gas, can be employed.

A combustion chamber **32** is provided immediately upstream of an outlet **34** of the sleeve **26**. Air and gas are mixed and ignited in the combustion chamber **32** as will be discussed in further detail herein. The resulting flame **35** is directed outwardly through the outlet **34** of the sleeve **26**. The outlet **34** can be positioned proximate any suitable receiving conduit or chamber such as that provided in a boiler, furnace, heat exchanger, kiln or the like, to perform useful work therein.

Turning now to FIG. **2**, the burner cartridge **28** is shown in detail. Burner cartridge **28** includes a supply conduit **36** having an inlet **38**, adapted to be connected to a supply of gas **39**, and an outlet cap **40**. In one preferred embodiment, the outlet cap **40** includes a plurality of radially directed apertures **42** through which the gas is dispersed. A back plate **44** is secured to the inlet **38** of the supply conduit **36** for attachment of the burner cartridge **28** to the housing **22**.

A flame rod assembly **46** is positioned proximate the outlet end **40** of the supply conduit **36** to detect and ensure the presence of a flame. Such flame rod assemblies **46** are conventional and may operate by providing a flame rod **48** which, upon being heated by the flame, directs a suitable signal to a controller **50** (FIG. **1**) of the burner **20**. The controller **50** may be in communication with a higher level integrated control system which may take advantage of the signal to provide an indication to an operator as to whether a flame is present.

A pilot assembly **54** is also provided proximate the outlet end **40** of the supply conduit **36**. The pilot assembly **54** provides initial ignition such that upon actuation of the motor **24**, and flow of gas through the gas supply conduit **36** and the outlet cap **40**, overall ignition of the burner **20** is insured. The pilot assembly **54** includes a housing **56**, a spark rod **58** and a gas supply conduit **60** having an inlet **61**, all of which will be described in further detail herein.

A flame retention or stabilizing plate, also know as a nozzle plate., **62** is also provided proximate the outlet cap **40** of the supply conduit **36**. As shown best in FIGS. **3** and **4**, the retention plate **62** includes a substantially triangular shaped central hub **64** having three sides **66**, **68**, and **70**. The hub **64** also includes three corners **72**, **74**, and **76** from which legs or spokes **78**, **80**, and **82** radially extend, respectively. A plurality of apertures **84** are provided in each of the spokes **78**, **80** and **82**. In the preferred embodiment, nine such apertures **84** are provided in a substantially rectangular configuration, although a different number of apertures, or configuration for the apertures, can be employed.

While the retention plate **62** is illustrated with the hub **64** being substantially triangularly shaped with three substantially rectangularly shaped spokes **78**, **80**, **82** extending radially therefrom, it is to be understood that the teachings of the invention encompass additional shapes which employ differently shaped central hubs from which a plurality of differently shaped spokes radially extend. In addition, a larger or smaller number of spokes **78**, **80**, **82** may be provided in such alternative embodiments.

As shown in FIG. **4**, the retention plate **62** also includes a large central aperture **86** which enables gas to flow therethrough when connected to the supply conduit **36**. The retention plate **62** may be connected to the supply conduit **36** by welding, fasteners, or the like.

Referring now to FIGS. **5–7**, the pilot assembly **54** is shown in detail. The housing **56** of the pilot assembly **54** is preferably of a T-shaped configuration, when shown in cross section (see FIG. **6**), and is preferably manufactured from cast iron. The housing **56** includes a main cylindrical member **87** having a first inlet **88**, a first outlet **90** directly opposite the first inlet **88**, and a second inlet **92** provided transverse to a longitudinal axis A defined by the first inlet **88** and the first outlet **90**. Such a T-shaped housing **56** is readily commercially available and typically includes a plurality of female threads in each of the first inlet **88**, first outlet **90**, and second inlet **92** to facilitate attachment to other conduits.

The spark rod **58** is connected to the first inlet **88**. The spark rod **58** includes a bushing **94** adapted to fit within the first inlet **88** to enable the spark rod **58** to be secured to the housing **56**. A conductor **98** passes through an outer insulated sheath **100** and terminates in a retention plate **102** having a substantially circular shape that is shown best in FIG. **7**.

As shown is FIG. **2**, the gas supply **60** is adapted to be connected to the second inlet **92**. Accordingly, gas passes through the second inlet **92**, into a central chamber **106**, and subsequently into a combustion chamber **108**. The combustion chamber **108** preferably includes a first zone **110** having a first diameter a, and a second zone **112** having a second diameter β. In the depicted embodiment of FIG. **2**, the second diameter β is less than the first diameter a, but it is to be understood that in alternative embodiments, the first diameter α may be greater than, or equal to, the second diameter β. By positioning the spark rod **58** within the housing **56** as described, a spark gap **114** is created between a circumferential surface **116** of the retention plate **102**, and an inner surface **118** of the first zone **110**. As shown in FIG. **7**, the spark gap **114** is annular in shape in that it extends around the entire circumference of the retention plate **102**.

In operation, the pilot assembly **24** is ignited by energizing the motor **24** and supplying combustible gas through the gas supply line **60** and into the combustion chamber **108**. When the motor **24** is energized, the fan connected thereto is caused to rotate within the housing **22**, which in turn directs a stream of air through the sleeve **26**. At the same time, the spark rod **58** is energized, which creates a sufficient voltage differential between the outer circumference **116** of the retention plate **102** and the inner circumference **118** of the first zone **110** such that a current flow arcs or jumps across the spark gap **114**, thereby igniting the gas. By providing the circumferential spark gap **114**, improved reliability and starting is provided over conventional spark plugs and rods which provide smaller, non-circumferential gaps. Moreover, the pilot assembly **54** is manufactured from low cost, readily available, components enabling the overall cost of the pilot assembly **54** to be maintained at a low level.

Once the pilot assembly **54** is ignited, the overall burner **20** can be ignited by providing gas through the main supply conduit **34**. This is typically accomplished by opening a valve **120** (see FIG. **1**) at an upstream end of the conduit **36**. Ignition of the pilot assembly **54** is verified by the flame sensing rod **48** and the controller **50** prior to opening of the valve **120**.

Referring to FIG. **3**, one of ordinary skill in the art will recognize that the retention plate **62** occupies a relatively small cross sectional area of the sleeve **26**, and preferably less than fifty percent of the cross-sectional area of the sleeve **26**. Major air passageways **122** are provided between adjacent spokes **78**, **80**, **82** wherein the retention plate **62** does not block the sleeve **26**. Accordingly, a relatively large volume of air can be forced by the motor **24** and fan through the major air passageways **122** and into the combustion chamber **32**. The overall output of the burner **20**, in terms of BTUs, is therefore greatly improved over typical burners of comparable size which typically include a circular retention plate substantially blocking the majority of the sleeve **26**.

By providing the retention plate **62** in a hub and spoke configuration, greater control over the resulting flame is provided, thereby improving flame stability. More specifically, the air flow created by the motor **24** is forced not only through the major air passageways **122**, but through the minor air passageways defined by the apertures **84** in each of the spokes **78**, **80** and **82**. This in turn creates three stabilizing air flowpaths tending to define an outer boundary for the resulting flame. Not only is the flame stabilized, but the flame is also centralized by such a retention plate **62** which in turn increases the overall BTU output of burner **20**.

FIGS. **8** and **9** depict alternative embodiments for the burner outlet **40**. In both embodiments the outlet cap **40** is substantially triangular in shape to conform to the shape of the retention plate **62**. More specifically, the outlet cap **40** includes three sides **130** surrounding a triangular body **132**. The outlet cap **40** also includes three truncated corners **144**, with one of the truncated corners **144** positioned proximate each one of the spokes **78**, **80**, **82** of the retention plate **62**. The outlet cap **40** is secured to the retention plate **62** with fasteners **145**. The caps **40** create distinct gas flow dispersion patterns to facilitate operation and tailor the burner **20** to a given application.

In FIG. **8**, a gas outlet **146** is centrally provided in each of the three sides **130**. A gas outlet **148** is provided in each of the truncated corners **144** as well. Each of the gas outlets **148** in the truncated corners **144** is larger than each of the gas outlets **146** in each of the sides **130**.

In FIG. **9**, each truncated corner **144** includes a flap **149** which forms multiple gas outlets **150**. One gas outlet **152** is provided in each of the sides **130**. Each of the gas outlets **152** in the sides **130** is substantially larger than the gas outlets **150** in the truncated corners **144**.

From the foregoing, one of skill in the art will recognize that the invention provides a burner with enhanced BTU output and flame stability, while doing so at a relatively low cost.

What is claimed is:

1. A burner assembly, comprising:

a substantially cylindrical combustion chamber;

a gas supply terminating in a gas supply outlet;

an air supply in fluid communication with the substantially cylindrical combustion chamber; and

a flame stabilizing plate disposed in the substantially cylindrical combustion chamber, the flame stabilizing plate having a central hub from which a plurality of spokes radially extend, major combustion air openings being defined by adjacent spokes of the plurality of spokes and the combustion chamber, minor combustion air openings being provided in each of the plurality of spokes, the flame stabilizing the plate occupying less than one-half of the cross sectional area of the substantially cylindrical combustion chamber.

2. The burner assembly of claim **1**, wherein the flame stabilizing plate is located upstream of the gas supply outlet.

3. The burner assembly of claim **1**, further including a motorized blower, the motorized blower generating the air supply to the combustion chamber.

4. The burner assembly of claim **1**, further including a pilot assembly positioned proximate the combustion chamber.

5. A burner assembly, comprising:

a substantially cylindrical chamber provided in a substantially cylindrical combustion chamber;

a gas supply terminating in a gas supply outlet;

an air supply in fluid connection with the combustion chamber; and

a flame stabilizing plate disposed in the substantially cylindrical combustion chamber, the flame stabilizing plate having a central hub from which a plurality of spokes radially extend, major combustion air openings being defined by adjacent spokes of the plurality of spokes and the combustion chamber, combustion air openings being provided in each of the plurality of spokes, wherein the central hub of the flame stabilizing plate is substantially triangular in shape with three angled coners, one of the plurality of spokes extending from each of the three angled coners.

6. The burner assembly of claim **5**, wherein each of the spokes includes nine apertures in a square configuration.

7. A burner assembly, comprising:

a substantially cylindrical chamber provided in a substantially cylindrical combustion chamber;

a gas supply terminating in a gas supply outlet;

an air supply in fluid connection with the combustion chamber; and

a flame stabilizing plate disposed in the substantially cylindrical combustion chamber, the flame stabilizing plate having a central hub from which a plurality of spokes radially extend, major combustion air openings being defined by adjacent spokes of the plurality of spokes and the combustion chamber, combustion air openings being provided in each of the plurality of spokes, wherein the flame stabilizing plate occupies approximately one half of the cross-sectional area of the substantially cylindrical combustion chamber.

8. A burner assembly, comprising:

a substantially cylindrical chamber provided in a substantially cylindrical combustion chamber;

a gas supply terminating in a gas supply outlet;

an air supply in fluid connection with the combustion chamber;

a flame stabilizing plate disposed in the substantially cylindrical combustion chamber, the flame stabilizing plate having a central hub from which a plurality of spokes radially extend, major combustion air openings being defined by adjacent spokes of the plurality of spokes and the combustion chamber, combustion air openings being provided in each of the plurality of spokes; and

a pilot assembly positioned proximate the substantially cylindrical combustion chamber, wherein the pilot assembly comprises:

a housing having first and second inlets and an outlet, the outlet being substantially cylindrical;

a gas supply connected to the first inlet; and

a spark rod connected to the second inlet, the spark rod having a substantially circular end plate positioned proximate the substantially cylindrical outlet, a circumferential spark gap being provided between the end plate and the outlet.

9. The burner assembly of claim **8**, wherein the substantially cylindrical outlet includes a first zone of a first diameter and a second zone of a second diameter, the second diameter being smaller than the first diameter, the first zone being closer to the end plate than the second zone.

10. The burner assembly of claim **8**, wherein the housing is a T-shaped fitting.

11. A burner assembly, comprising:

a substantially cylindrical chamber provided in a substantially cylindrical combustion chamber;

a gas supply terminating in a gas supply outlet;

an air supply in fluid connection with the combustion chamber;

a flame stabilizing plate disposed in the substantially cylindrical combustion chamber, the flame stabilizing plate having a central hub from which a plurality of spokes radially extend, major combustion air openings being defined by adjacent spokes of the plurality of spokes and the combustion chamber, combustion air openings being provided in each of the plurality of spokes; and

a gas outlet cap proximate the gas supply outlet, the gas outlet cap being substantially circular with a cylindrical side wall, at least one gas supply outlet being provided in the cylindrical side wall.

12. A burner assembly, comprising:

a substantially cylindrical chamber provided in a substantially cylindrical combustion chamber;

a gas supply terminating in a gas supply outlet;

an air supply in fluid connection with the combustion chamber;

a flame stabilizing plate disposed in the substantially cylindrical combustion chamber, the flame stabilizing plate having a central hub from which a plurality of spokes radially extend, major combustion air openings being defined by adjacent spokes of the plurality of spokes and the combustion chamber, combustion air openings being provided in each of the plurality of spokes; and

a gas outlet cap proximate the gas supply outlet, the gas outlet cap being substantially triangular with three side walls, at least one gas supply outlet being provided in each of the side walls.

13. In a burner assembly having a nozzle housing having an inlet and an outlet, a blower motor connected to the inlet, a gas supply conduit disposed in a nozzle housing, and a combustion chamber defined by the nozzle housing downstream of a gas supply conduit, the improvement comprising:

a nozzle plate disposed in the nozzle housing, the nozzle plate having a central hub with a plurality of spokes radially extending therefrom, each spoke including at least one aperture;

a plurality of major air pathways defined by adjacent spokes and the nozzle housing, the plurality of major air pathways traversing through the combustion chamber to approximately define an outer boundary of a centralized flame;

at least one minor air pathway defined by each of the spoke apertures.

14. In a burner assembly having a nozzle housing having an inlet and an outlet, a blower motor connected to the inlet, a gas supply conduit disposed in the nozzle housing, and a combustion chamber defined by the nozzle housing downstream of the gas supply conduit, the improvement comprising:

a nozzle plate disposed in the nozzle housing, the nozzle plate having a central hub with a plurality of spokes radially extending therefrom, each spoke including at least one aperture, wherein the nozzle plate central hub is substantially triangular in shape with three angular coners, and wherein three spokes are provided, one of the spokes extending from each of the coners;

a plurality of major air pathways defined by adjacent spokes and the nozzle housing; and

at least one minor air pathway defined by each of the spoke apertures.

15. The improvement of claim **14**, wherein each spoke includes a plurality of apertures provided in a substantially rectangular configuration.

16. In a burner assembly having a nozzle housing having an inlet and an outlet, a blower motor connected to the inlet, a gas supply conduit disposed in the nozzle housing, and a combustion chamber defined by the nozzle housing downstream of the gas supply conduit, the improvement comprising:

a nozzle plate disposed in the nozzle housing, the nozzle plate having a central hub with a plurality of spokes radially extending therefrom, each spoke including at least one aperture, wherein the nozzle housing has a cross-sectional area, and wherein the nozzle plate occupies approximately half of the nozzle housing cross-sectional area;

a plurality of major air pathways defined by adjacent spokes and the nozzle housing; and

at least one minor air pathway defined by each of the spoke apertures.

17. In a burner assembly having a nozzle housing having an inlet and an outlet, a blower motor connected to the inlet, a gas supply conduit disposed in the nozzle housing, and a combustion chamber defined by the nozzle housing downstream of the gas supply conduit, the improvement comprising:

a nozzle plate disposed in the nozzle housing, the nozzle plate having a central hub with a plurality of spokes radially extending therefrom, each spoke including at least one aperture;

a plurality of major air pathways defined by adjacent spokes and the nozzle housing; and

at least one minor air pathway defined by each of the spoke apertures, wherein the plurality of major pathways have a first combined cross-sectional area and the plurality of minor pathways have a second combined cross-sectional area, the ratio of the first combined cross-sectional area to the second combined cross-sectional area being at least two to one.

* * * * *